CHAPTER 2
INCINERATOR EMISSIONS

2-1. Incineration

This chapter describes and quantifies whenever possible the air pollution particulate emissions which are the direct result of the incineration process.

a. Incineration process. The incineration process consists of burning solid, semisolid, liquid, or gaseous waste to produce carbon dioxide, water, and ash. It is an efficient means of reducing waste volume. The solid, incombustible residue of incineration is inert, sanitary, and sensibly odorless.

b. Emissions. Incineration contributes to air pollution. The polluting emissions are ash, hydrocarbons, sulfur oxides (SO_X), nitrous oxides (NO_X), chlorides, and carbon monoxide. Estimating absolute quantities of these pollutants is not an exact science, hut historical testing data from typical incinerators allow estimates of emissions to be made. Also, measurement methods for incinerator emissions are sufficiently advanced to permit actual data to be obtained for any existing incinerator. These measurements are preferred in all cases over analytical estimates.

c. Pollution codes. Air pollution particulate emissions must be considered in regard to federal, state and local pollution codes. In general, incinerators cannot meet current pollution code requirements without particulate control devices.

2-2. Types of incinerator waste materials

Waste materials are classified as shown in table 2-1. An ultimate analysis of a typical general solid waste is shown in table 2-2. Because of the wide variation in composition of waste materials, an analysis of the actual material to be incinerated should be made before sizing incineration equipment.

Table 2–2

Ultimate analysis of a typical general solid waste

Moisture	35.00%
Carbon	20.00%
Oxygen	18.00%
Hydrogen	2.50%
Nitrogen	0.60%
Sulfur	0.06%
Noncombustibles	23.84%
	100.00%

From: Environmental Protection Agency, "Control Techniques for Particulate Emissions for Stationary Sources"

2-3. Function of incinerators

Incinerators are engineered apparatus capable of withstanding heat and are designed to effectively reduce solid, semi-solid, liquid, or gaseous waste at specified rates, so that the residues contain little or no combustible material. In order for an incinerator to meet these specifications, the following principles of solid fuel combustion generally apply:

— Air and fuel must be in the proper proportion,
— Air and fuel, especially combustible gases, must be properly mixed,
— Temperatures must be high enough to ignite both the solid fuel and the gaseous components,
— Furnace volumes must permit proper retention time needed for complete combustion,
— Furnace configurations must maintain ignition temperatures and minimize fly-ash entrainment.

2-4. Effect of waste properties

The variability of chemical and physical properties of waste materials, such as ash content, moisture content, volatility, burning rate, density, and heating value, makes control of incineration difficult. All of these factors affect to some degree the operating variables of flame-propagation rate, flame travel, combustion temperature, combustion air requirements, and the need for auxiliary heat. Maximum combustion efficiency is maintained primarily through optimum incinerator design.

2-5. Types of incinerators

a. Municipal incinerators. Incinerators are classified either as large or small units, with the dividing point at a processing rate of 50 tons of waste per day. The trend is toward the use of the smaller units because of their lower cost, their simplicity, and lower air emission control requirements. There are three major types of municipal incinerators.

(1) *Rectangular incinerators.* The most common municipal incinerator is the rectangular type. The multiple chamber units are either refractory lined or water cooled and consist of a combustion chamber followed by a mixing chamber. The multicell units consist of two or more side-by-side furnace cells connected to a common mixing chamber. Primary air is fed under the grate. Secondary air is added in the mixing chamber to complete combustion. A settling chamber often follows the mixing chamber. Ash is removed from pits in the bottom of all of the chambers.

TABLE 2-1

WASTE CLASSIFICATIONS

TYPE	DESCRIPTION	PRINCIPAL COMPONENTS	APPROXIMATE COMPOSITION % BY WEIGHT	MOISTURE CONTENT %	INCOMBUSTIBLE SOLIDS %	BTU VALUE/ LB OF REFUSE AS FIRED
0	Trash	Highly combustible waste; paper, wood, cardboard cartons, including up to 10% treated papers, plastic or rubber scraps; commercial and industrial sources.	Trash 100	10	5	8500
1	Rubbish	Combustible waste, paper, cartons, rags, wood scraps, combustible floor sweepings, domestic, commercial, and industrial sources.	Rubbish 80 Garbage 20	25	10	6500
2	Refuse	Rubbish and garbage; residential sources.	Rubbish 50 Garbage 50	50	7	4300
3	Garbage	Animal and vegetable wastes; restaurants, hotels, markets; institutional commercial, and club sources	Garbage 65 Rubbish 35	70	5	2500
4	Animal solids and organic waste	Carcasses, organs, solid organic wastes; from hospital, laboratory, abattoirs, animal pounds and similar sources.	Animal and Human Tissue 100	85	5	1000
5	Gaseous, liquid or semi-liquid wastes	Industrial process wastes such as, tar, paint, solvent, sludge and fumes.	Variable	Dependent on predominant components	Varies according to wastes	Varies according to wastes
6	Semi-solid and solid wastes	Industrial process wastes, such as, rubber, plastic and wood.	Variable	Dependent on predominant components	Varies according to wastes	Varies according to wastes

U. S. Army Corps of Engineers.

(2) *Vertical circular incinerators.* Waste is usually fed into the top of the refractory lined chamber. The grate consists of a rotating cone in the center surrounded by a stationary section with a dumping section around it. Arms attached to the rotating cone agitate the waste and move the ash to the outside. Primary air is fed underneath the grate. Overfire air is fed into the upper section of the chamber.

(3) *Rotary kiln incinerators.* Rotary kiln incinerators are used to further the combustion of waste that has been dried and partially burned in a rectangular chamber. The waste is mixed with combustion air by the tumbling action of the kiln. Combustion is completed in the mixing chamber following the kiln where secondary air is added. The ash is discharged at the end of the kiln.

b. Industrial and commercial incinerators. Industrial and commercial incinerators generally fall into six categories. The capacities of these incinerators generally range from a half to less than 50 tons per day. They are usually operated intermittently.

(1) *Single chamber incinerators.* Single chamber incinerators consist of a refractory lined combustion chamber and an ash pit separated by a grate. There is no separate mixing

chamber. An auxiliary fuel burner is normally provided underneath the grate. The units are normally natural draft (no fans). Emissions from single chamber units are high because of incomplete combustion.

(2) *Multiple chamber incinerators.* Multiple chamber refractory lined incinerators normally consist of a primary chamber, a mixing chamber and a secondary combustion chamber. The primary chamber is similar to a single chamber unit. Air is fed under the grate and through overfire air ports. Secondary air is added in the mixing chamber. Combustion is completed in the secondary combustion chamber where some settling occurs. These units are also normally natural draft.

(3) *Conical incinerators.* Conical incinerators known commonly as "tee-pee" burners have been used primarily in the wood products industry to dispose of wood waste. Since they cannot meet most local particulate emission requirements, and since wood waste is becoming more valuable as a fuel, conical incinerators are being phased out.

(4) *Trench incinerators.* Trench incinerators are used for disposal of waste with a high heat content and a low ash content. The incinerator consists of a U-shaped chamber with air nozzles along the rim. The nozzles are directed to provide a curtain of air over the pit and to provide air in the pit.

(5) *Controlled-air incinerators.* Controlled-air incinerators consist of a refractory lined primary chamber where a reducing atmosphere is maintained and a refractory lined secondary chamber where an oxidizing atmosphere is maintained. The carbon in the waste burns and supplies the heat to release the volatiles in the waste in the form of a dense combustible smoke. Overfire air is added between chambers. The smoke is ignited in the secondary chamber with the addition of air. Auxiliary fuel burners are sometimes provided in the secondary chamber if the mixture does not support combustion. Air for this type of incinerator is provided by a forced draft fan and is controlled by dampers in order to provide the proper distribution. Controlled-air incinerators are efficient units with low particulate emission rates.

(6) *Fluidized bed incinerators.* Fluidized bed incinerators consist of a refractory lined vertical cylinder with a grid in the lower part that supports a bed of granular material, such as sand or fine gravel. Air is blown into the chamber below the grid causing the bed to fluidize. Waste is fed above the bed and then mixes with the media where it burns. Fluidized bed incinerators are normally self sustaining and require an auxiliary fuel burner only for startup. Fluidizing air is supplied by a centrifugal blower. Ash leaves the fluidized bed incinerator when it becomes fine enough to be carried out by the flue gas. Fluidized bed incinerators are capable of burning most types of liquid or solid waste.

c. Sludge incinerators. Sludge incinerators handle materials high in water content and low in heat content. Two types of incinerators are normally used for sludge incineration.

(1) *Multiple hearth incinerators.* Multiple hearth incinerators consist of vertically stacked grates. The sludge enters the top where the exiting flue gas is used to drive off the moisture. The burning sludge moves through the furnace to the lower hearths. Ash is removed from under the last hearth.

(2) *Fluidized bed incinerator.* Fluidized bed incinerators are particularly well suited for sludge disposal because of the high heat content of the bed media. Heat from the combustion of the sludge is transferred to the bed media. This heat is then transferred back to the incoming sludge, driving off the moisture.

2-6. Particulate emission standards

The Clean Air Act requires all states to issue regulations regarding the amount of particulate emission from incinerators. Each state must meet or exceed the primary standards set forth by the federal act, limiting particulate emissions for incinerators with a charging rate of more than 50 tons per day of solid to .08 grains per standard cubic foot (gr/std ft^3) of dry gas at 12 percent carbon dioxide (CO_2). Federal guidelines for sewage sludge incinerators limit emissions to 1.3 pounds (lbs) per ton of dry sludge input and opacity to 20 percent maximum. No federal guidelines currently exist for gaseous emissions. State and local regulations may meet or exceed the federal guidelines. These regulations are subject to change and must be reviewed prior to selecting any air pollution control device.

2-7. Particulate emission estimating

In order to select a proper pollution control device, the quantities of particulate emissions from an incinerator must be measured or estimated. Measurement is the preferred method. For new incinerator installations where particulate emissions must be estimated, tables 2-3 and 2-4 should be used unless concurrent data guaranteed by a qualified Vendor is provided.

a. Factors affecting emission variability. The quantity and size of particulate emissions leaving the furnace of an incinerator vary widely, depending upon

TABLE 2-3

EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROLS[a]

Incinerator Type	Particulates lb/ton	Sulfur oxides[b] lb/ton	Carbon monoxide lb/ton	Hydrocarbons[c] lb/ton	Nitrogen oxides[d] lb/ton
Municipal					
Multiple chamber, uncontrolled	30	2.5	35	1.5	3
With settling chamber and water spray system[e]	14	2.5	35	1.5	3
Industrial/Commercial					
Multiple chamber	7	2.5[f]	10	3	3
Single chamber	15	2.5[f]	20	15	2
Wood	13	0.1[g]	NA[h]	NA	4
Rubber tires	138	NA	NA	NA	NA
Municipal refuse	37	2.5[f]	NA	NA	NA
Controlled air	1.4	1.5	Neg	Neg	10
Flue-fed single chamber	30	0.5	20	15	3
Flue-fed (modified)[i]	6	0.5	10	3	10
Domestic single chamber					
Without primary burner	35	0.5	300	100	1
With primary burner	7	0.5	Neg	2	2
Pathological	8	Neg	Neg	Neg	3

a Average factors given based on EPA procedures of incinerator stack testing.
b Expressed as sulfur dioxide.
c Expressed as methane.
d Expressed as nitrogen dioxide.
e Most municipal incinerators are equipped with at least this much control.
f Based on municipal incinerator data
g Based on data for wood combustion in conical burners.
h Not available.
i With afterburners and draft controls

From: Environmental Protection Agency, "Compilation of Air Emission Factors".

TABLE 2-4

EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS

Pollutant	Emissions* Uncontrolled lb/ton
Particulate	100
Sulfur dioxide	1
Carbon monoxide	Neg
Nitrogen oxides (as NO_2)	6
Hydrocarbons	1.5
Hydrogen chloride gas	1.5

* Unit weights in terms of dried sludge.

From: Environmental Protection Agency, "Compilation of Air Emission Factors".

such factors as incinerator design, refuse type, incinerator capacity, method of feeding, and method of operation. Improved incinerator performance reduces both dust loading and mean particle size.

(1) *Incinerator capacity.* Large incinerators burn refuse at higher rates creating more turbulent gas flow conditions at the grate surface. Rapid, turbulent, combustion aided by the use of more underfire air causes particle suspension and carry over from the incinerator grate surface resulting in higher emission rates for large incinerators.

(2) *Underfire air flow.* The effect of increasing underfire grate air flow is to increase particulate emission rate.

(3) *Excess air* Excess air is used to control combustion efficiency and furnace temperatures. Incinerators are operated at levels of excess air from 50 percent to 400 percent. However, particulate emission levels increase with the amount of excess air employed. Increases in excess air create high combustion gas velocities and particle carry over. Excess air is important as a furnace temperature control because incomplete combustion will occur at furnace temperatures below 1400 degrees Fahrenheit, and ash slagging at the grate surface and increased NO_X emissions will occur above furnace temperatures of 1900 degrees Fahrenheit.

(4) *Opacity.* For information on the use of visible opacity measurement as an aid to achieving efficient combustion, see paragraph 3-8.

b. Data reduction. The state regulations for particulate emissions are expressed in a variety of units. The following techniques permit the user to reduce particulate test data to grains per dry standard cubic foot at 12 percent CO_2, as well as to convert other particulate concentration units, as used by some states, to this basis.

(1) Test data conversion to grains per dry standard cubic foot at 12 percent CO2. Equation 2-1 applies.

$$C_s \text{ at 12 percent } CO_2 = \frac{0.68}{CO_2} \times \frac{(t_m + 460)}{p} \times C \qquad \text{(eq. 2-1)}$$

where: C_s at 12 percent CO2 particulate concentration in grains per dry standard cubic foot at gas conditions corrected to 12 percent CO_2 and standard temperature of 68 degrees Fahrenheit.

C = particulate concentration at test conditions in grains per dry cubic foot of gas

tm = gas temperature at the test equipment conditions

CO_2 = percent by volume of the CO_2 in the dry gas

p = barometric pressure in inches of mercury at the test equipment conditions.

(2) To convert particulate loadings given as pounds per 1000 pounds of dry gas at 50 percent excess air, equation 2-2 applies.

$$C_s \text{ at 12 percent } CO_2 = \frac{C \text{ at 50 percent EA}}{CO_2} \times .325 \times \frac{A_T}{A_A} \times M \quad \text{(eq. 2-2)}$$

where: C at 50 percent EA = pounds of particulate per 100 pounds of gas at 50 percent excess air

$\frac{A_T}{A_A}$ = theoretical air required per actual air used

M = Molecular weight of the gas sample

$$\frac{A_T}{A_A} = \frac{N_2 - 3.788\,(O_2 - .5\,CO)}{N_2} \quad \text{(eq. 2-3)}$$

$$M = .16\,CO_2 + .04\,O_2 + 28 \quad \text{(eq. 2-4)}$$

where: N_2 = percent N_2 from Orsat analysis

O_2 = percent O_2 from Orsat analysis

CO = percent CO from Orsat analysis

CO_2 = percent CO_2 from Orsat analysis

(3) To convert grains per dry standard cubic foot at 50 percent excess air to grains per dry standard cubic foot at 12 percent CO_2, equation 2-5 applies.

$$C_s \text{ at 12 percent } CO_2 = \frac{18 \times C_s \text{ at 50 percent EA}}{CO_2} \times \frac{A_T}{A_A} \quad \text{(eq. 2-5)}$$

(4) To convert pounds of particulate per ton of refuse charged to grains per dry standard cubic foot at 12 percent CO_2, equation 2-6 applies.

$$C_s \text{ at 12 percent } CO_2 = \frac{\text{lbs of particulate}}{\text{tons of refuse}} \times \frac{.42 \times 10^6}{GCV} \times \frac{1}{F_c} \quad \text{(eq. 2-6)}$$

where: GCV = gross calorific value of waste, British thermal units (Btu)/lb

F_c = carbon F factor, std ft^3/million (MM) Btu

$$F_c = \frac{0.321 \times 10^6 \times \text{percent carbon}}{GCV} \quad \text{(eq. 2-7)}$$

Percent carbon is by weight from the ultimate analysis of the refuse. The GCV and tons of refuse must be consistent with the ultimate analysis. If the ultimate analysis is on a dry basis, the GCV and tons of refuse must be on a dry basis.

(5) To convert grains per dry standard cubic foot at 7 percent O_2 to grains per dry standard cubic foot at 12 percent CO_2, equation 2-8 applies.

$$C_s \text{ at 12 percent } CO_2 = 1.714 \times C_s \text{ at 7 Percent } O_2 \times \frac{O_2}{CO_2} \quad \text{(eq. 2-8)}$$

(6) To convert pounds of particulate per million British thermal units fired to grains per dry standard cubic foot at 12 percent CO_2, equation 2-9 applies.

$$C_s \text{ at 12 percent } CO_2 = \frac{\text{lbs of particulate}}{\text{MMBtu}} \times \frac{840}{F_c} \quad \text{(eq. 2-9)}$$

2-8 Sample calculations

a. An industrial multichamber incinerator burns a type I waste at 10 percent moisture of the analysis shown below. What is the estimated particulate emission rate in grains per dry standard cubic foot at 12 percent CO_2?

Waste Analysis (Percent by Weight on Wet Basis)

Carbon	50 percent
Heating value	8500 Btu/lb

(1) Table 2-3 lists industrial multichamber incinerators as having a particulate emission factor of 7 lb/ton of refuse.

(2) Using equation 2-7,

$$F_c = \frac{0.321 \times 10^6 \times 50}{8500} = 1888$$

(3) Using equation 2-6,

$$C_s \text{ at 12 percent } CO_2 = 7 \times \frac{.42 \times 10^6}{8500} \times \frac{1}{1888} = 0.183 \text{ gr/std ft}^3$$

b. Test data from an incinerator indicates a particulate concentration of 0.5 gr/ft^3 at 9 percent CO_2. Correct the particulate concentration to grains per dry standard cubic foot at 12 percent CO_2. Test conditions were at 72 degrees Fahrenheit and a barometric pressure of 24 inches of mercury.

(1) Using equation 2-1,

$$C_s \text{ at 12 percent } CO_2 = 0.5 \times \frac{0.68}{9} \times \frac{(72 + 460)}{24}$$

$$= 0.84 \text{ gr/std ft}^3$$

c. The emission rate of an incinerator is 10 lb/1000 lb of dry flue gas at 50 percent excess air. The Orsat analysis is 8.0 percent O_2, 82.5 percent N_2, 9.5 percent CO_2 and 0 percent CO. Convert the emission rate to grains per dry standard cubic foot at 12 percent CO_2.

(1) Using equation 2-3,

$$\frac{A_T}{A_A} = \frac{82.5 - 3.788(8.0 - .5(0))}{82.5} = 0.633$$

(2) Using equation 2-4,

M=.16(9.5) + .04(8.0) + 28 = 29.84

(3) Using equation 2-2,

$$C_s \text{ at 12 percent } CO_2 = \frac{10}{9.5} \times .325 \times .633 \times 29.84$$

$= 6.46$ gr/std ft_3

d. An incinerator burning waste of the analysis shown below has a measured emission rate of 5 pounds/ MMBtu. What is the expected particulate emission rate in grains per dry standard cubic foot at 12 percent CO_2?

Waste Analysis

Carbon	35 percent by weight on dry basis
Heating Value	6500 Btu/pound as fired
Moisture	21 percent

(1) In order to use equation 2-7, the percent carbon and the heating value must be on the same basis.

$$\text{Percent C on wet basis} = \frac{35 \times (100\text{-}21)}{100} = 28$$

(2) Using equation 2-7,

$$F_c = \frac{0.321 \times 10^6 \times 28}{6500} = 1382$$

(3) Using equation 2-9.

$$C_s \text{ at 12 percent } CO_2 = 5 \times \frac{840}{1383}$$

$$= 3.04 \text{ gr/std ft}^3$$